Characteristics of Dry-Wet Changes and Their Impacts in the Three-River-Source Region: Postprint

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Abstract

Under the influence of global climate change, the meteorological and hydrological characteristics of the Three-River Source Region in the eastern Tibetan Plateau have undergone significant changes over the past few decades. Dry-wet conditions reflect regional moisture and climate regimes, and investigating the characteristics of dry-wet variations against the backdrop of climate warming holds important value for revealing regional environmental responses to climate change and hydro-ecological evolution issues. Utilizing hydrometeorological data from the past 58 years, this study adopts the Holdridge Potential Evapotranspiration Rate (PER) to represent aridity, and employs cumulative anomaly, Pettitt change point detection, and inverse distance weighting methods to examine the characteristics and spatial distribution of dry-wet changes in the Three-River Source Region based on PER, while exploring the potential impacts of variations in meteorological elements on dry-wet changes under climate change. The results demonstrate that: (1) Temporally, the overall PER values in the Three-River Source Region show a significant increasing trend ($P < 0.05$), with an abrupt change detected in 1997 ($P < 0.1$), indicating a tendency toward aridification; (2) Spatially, PER exhibits an increasing gradient from southeast to northwest, with significant increasing trends at most stations; (3) Through correlation analysis, PER is found to be significantly negatively correlated with precipitation and relative humidity, and significantly positively correlated with temperature and sunshine duration; temperature is the main factor contributing to the warming-drying trend in the Three-River Source Region.

Full Text

Preamble

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Characteristics of Wetness/Dryness Variation and Their Influences in the Three-River Headwaters Region

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Abstract

Global climate change has caused significant alterations in the meteorological and hydrological characteristics of the Three-River Headwaters region (TRH) located in the eastern Tibetan Plateau over the past few decades. Wetness/dryness conditions reflect regional moisture balance and climate characteristics, and studying their response to climate warming is crucial for understanding regional environmental responses to climate change and eco-hydrological evolution issues. Using daily hydrological and meteorological data from 1957-2014, this study analyzed wetness/dryness variations and spatiotemporal characteristics of the potential evapotranspiration rate (PER) in the TRH based on the Holdridge life zone model. The Pettitt test, accumulated anomaly analysis, and linear trend detection were employed to identify change points and long-term variation trends of PER and other factors, while inverse distance weighting (IDW) was used to analyze the spatial distribution and variation characteristics of PER. Regression analysis estimated the contribution rates of meteorological factors to PER changes, and we discussed how variations in meteorological elements influenced wetness/dryness under climate change.

The results show: (1) Temporally, PER in the TRH region increased significantly ($p < 0.05$), with a change point detected in 1997 ($p < 0.1$). PER exhibited a relatively slow decline during 1957-1997, rose in the 1970s-1980s, and then showed a significant increase after 1998, indicating intensified drying. (2) Spatially, mean annual PER decreased from southeast to northwest, with most stations recording increasing PER trends, though growth rates were relatively slow in the north and southwest. (3) PER was positively correlated with precipitation and relative humidity, and negatively correlated with air temperature and sunshine duration. Among these factors, temperature was the primary natural factor influencing wetness/dryness changes. Attribution analysis revealed that PER was primarily influenced by air temperature and wind speed, with contribution rates of 48% and 42%, respectively, though the wind speed contribution was not statistically significant. Thus, rising temperature was concluded to be the main factor related to warming and drying in the TRH region during 1957–2014.

This study demonstrates that the Holdridge life zone model can be utilized to evaluate wetness/dryness characteristics in the TRH region. Analysis of warming and drying impacts on the hydrological and ecological environment showed that ecological problems caused by drying—such as changes in soil water-thermal characteristics and hydrological regimes, vegetation degradation, wetland shrinkage, and biodiversity loss—are intensifying. To mitigate drought effects, protection measures should be implemented, including reducing human intervention, increasing pasture restoration, emphasizing biodiversity protection, modifying weather in suitable areas, and filling reservoirs to protect water sources.

Keywords: Three-River Headwaters; potential evapotranspiration rate (PER); dryness/wetness variation; Holdridge life zone model

1. Study Area Overview

The Three-River Headwaters region is the source area of the Yangtze, Yellow, and Lancang Rivers and constitutes an important water source area in China. The Qinghai Three-River Headwaters Ecological Protection Zone covers approximately 363,000 km^2, including all administrative regions of Yushu Tibetan Autonomous Prefecture, Guoluo Tibetan Autonomous Prefecture, Hainan Tibetan Autonomous Prefecture, and Huangnan Tibetan Autonomous Prefecture, plus Tanggula Town in Golmud City. The region exhibits typical plateau continental climate characteristics, with elevations mostly above 4,000 m, annual sunshine duration of 2,300–2,900 hours, and mean annual temperatures ranging from -5.4 to 7.5°C. Precipitation shows large interannual variability, with an average of 404 mm. The geographical location is 31.39°–36.56°N, 89.45°–102.23°E. [Figure 1: see original paper] shows the geographical location and distribution of meteorological stations.

2. Data Sources

Measured precipitation data were obtained from daily meteorological records provided by the China Meteorological Data Service Center. To ensure data continuity and consistency, the Zhiduo station was excluded due to relocation. Given varying data start times across stations and occasional missing measurements, this analysis used high-quality continuous records from 1957–2014, with missing data interpolated from adjacent or nearby stations.

3. Research Methods

3.1 Holdridge Potential Evapotranspiration Rate (PER) Method

The Holdridge method uses three climate parameters, with PER representing dryness. The method determines Annual Bio-temperature (ABT), Potential Evapotranspiration (PE), and PER, defined as follows:

PER represents dryness, where PE is potential evapotranspiration and P is annual precipitation. This study employed the model modified by Zhang Xinshi for the Qinghai-Tibet Plateau, which considers vegetation and other factors. The modified method comprehensively incorporates temperature, precipitation, and other factors affecting wetness/dryness changes, aligning with the actual conditions of the TRH region where dryness is primarily caused by rising temperatures, and has clear physical and ecological significance.

ABT is the heat index and primary temperature boundary for plant growth, calculated as the daily average of accumulated temperature. Holdridge discovered a proportional relationship between PE and temperature, expressed as PE = f(ABT). Daily mean temperature (t) is used when 0°C $\leq$ t $\leq$ 30°C (i = 1,2, ···,365), providing higher precision than monthly averages. shows the latitude, longitude, elevation, and meteorological elements of national meteorological stations in the TRH region. presents the classification criteria for wetness/dryness conditions represented by PER values.

3.2 Accumulated Anomaly Trend Test

Accumulated anomaly is a visual method for trend identification. For a sequence x, the accumulated anomaly at time t is calculated as the cumulative sum of deviations from the mean. Plotting these values produces an accumulated anomaly curve that can identify trend changes and potential mutation points.

3.3 Pettitt Mutation Point Test

The Pettitt test is a non-parametric method for identifying change points in sequences. The statistical parameter K represents the cumulative count of instances where values at time i are greater or less than those at time j. A potential mutation point T satisfies K = Max|K |. The significance of the change point is tested using p-values.

3.4 Inverse Distance Weighting (IDW) Method

IDW is used for spatial interpolation of factors. The method is more accurate and smoother than Thiessen polygon interpolation. The formula is:

$Z = \Sigma(Z / D\hat{}\beta) / \Sigma(1 / D\hat{}\beta)$

where Z is the target point value, Z is the value at point i, D is the distance from point i to target point p, β is the exponent (typically 2), and N is the number of meteorological stations.

4. Results and Analysis

4.1 Temporal Variation of PER

Using Thiessen polygons to weight 18 meteorological stations, the weighted annual average PER was calculated. The multi-year average PER ranged from 4.17-6.54, indicating overall arid conditions. The lowest value was 4.17 (1976) and highest was 7.56 (2000). PER showed an increasing trend from 1957-2014, with a slow decline during 1957-1998, a brief rise in the 1970s-1980s, and significant increase after 1998, indicating intensified drought. [Figure 2: see original paper] shows the trend and moving average test of PER from 1957-2014.

Accumulated anomaly analysis revealed a significant fluctuation around 1993, with the accumulated anomaly value increasing sharply and reaching an extreme in 1997. The Pettitt test further confirmed the mutation point occurred in 1997 ($p < 0.1$), consistent with the accumulated anomaly results. This indicates drought conditions in the TRH region began intensifying from the mid-to-late 1990s. Studies suggest this is linked to global warming and the 1997-1998 El Niño event, which weakened the Indian summer monsoon and reduced precipitation.

4.2 Spatial Variation Characteristics

The spatial distribution of multi-year average PER in the TRH region shows a decreasing trend from southeast to northwest. The most arid areas are in the northern Guizhou region (note: likely referring to Guinan or similar location in the original text) with PER values of 10.7-20.8, while the southeastern Jiuzhi area is semi-humid with PER of 2.5-4.1. Most stations show increasing PER trends, with the highest growth rates in central Yushu (0.30/10a, $p < 0.05$) and Qumalai (0.25/10a, $p < 0.05$). The slowest growth occurs in the northwest (Wudaoliang, -0.09/10a) and southwest, where drought intensification is relatively slow. [Figure 4: see original paper] shows the spatial variation of PER in the TRH region from 1957-2014.

4.3 Spatiotemporal Variation of Meteorological Factors

Precipitation is the primary water source, decreasing from southeast to northwest (456 mm in eastern Jiuzhi to 254-413 mm in the northwest). The spatial distribution of PER is opposite to precipitation. Temperature decreases from east to west, ranging from 7.5°C in eastern Guizhou to -5.2°C in northwestern Wudaoliang, increasing at 0.29°C/10a ($p < 0.01$). Sunshine duration increases from southeast to northwest, averaging 2,588 hours annually, with highest values in Qabqa and Tuotuohe (2,938 hours). Wind speed and relative humidity also show southeast-to-northwest gradients, though wind speed has decreased slightly at -0.05 m/s/10a ($p < 0.01$).

4.4 Correlation Analysis

Spearman correlation analysis shows PER is significantly positively correlated with air temperature ($r = 0.334$, $p < 0.01$) and sunshine duration ($r = 0.348$, $p < 0.01$), and negatively correlated with precipitation ($r = -0.523$, $p < 0.001$) and relative humidity ($r = -0.321$, $p < 0.05$). Wind speed shows no significant correlation. Partial correlation analysis confirms temperature is the dominant factor controlling PER changes. and present the correlation and partial correlation matrices.

4.5 Attribution Analysis

Regression analysis estimates factor contributions to PER: temperature (48.7%, $p < 0.01$), wind speed (42.3%, not significant), precipitation (2.3%), sunshine duration (0.01%), and relative humidity (0.1%). Other factors account for 6.97%, possibly due to human activities or anomalous climate. shows the contribution rates of each factor.

5. Discussion

5.1 Applicability of Holdridge PER Method in the TRH Region

The Holdridge PER method effectively characterizes climate dryness/wetness in the TRH region, showing good correspondence with precipitation, sunshine, and other factors. While the method doesn' t explicitly consider radiation and elevation effects, its applicability is validated for this region. Future research incorporating these factors could improve performance.

5.2 Impacts of Climate Warming and Drying on Ecological Environment

The TRH region' s temperature rise exceeds global and national averages, with significant warming-drying impacts on ecosystems. Warming-drying may reduce water supply, accelerate frozen soil thawing, alter soil water-thermal processes, decrease vegetation cover, and reduce biodiversity. Wetland shrinkage is a major consequence, with studies showing Tibetan Plateau wetlands have shrunk by 10%. The feedback between ecosystems and climate change becomes increasingly complex, threatening regional ecological security.

5.3 Response Measures for Warming and Drying

To address intensifying climate warming and drying in this sensitive region, comprehensive measures are needed: (1) Enhanced monitoring using remote sensing and advanced observations for real-time data; (2) Improved ecological protection mechanisms and research on climate-hydrology-environment interactions; (3) Reduced greenhouse gas emissions and prohibition of overgrazing; (4) Artificial weather modification in suitable areas to improve surface moisture; (5)

Integrated policy measures to effectively control human activities harming the ecological environment.

6. Conclusions

Using the Holdridge life zone model and PER as a dryness index, this study analyzed wetness/dryness variation characteristics and distribution in the TRH region from 1957-2014, revealing responses to meteorological factors and causes of warming-drying.

1. **Temporal trends**: PER showed an overall increasing trend, with a slow decline during 1957–1997, brief recovery in the 1970s–1980s, and significant increase after 1998. A mutation point occurred in 1997, after which the drying trend intensified.
2. **Spatial patterns**: PER decreases from southeast to northwest. The most arid areas are in the northern region, while the southeast is semi-humid. Most areas show increasing PER, with the fastest growth in central regions and slower growth in the northwest and southwest.
3. **Meteorological responses**: PER is significantly positively correlated with temperature and sunshine duration, and negatively correlated with precipitation and relative humidity. Temperature is the dominant factor, contributing 48.7% to PER increase.
4. **Ecological implications**: Intensified warming-drying will alter soil water-thermal conditions, accelerate vegetation degradation and wetland shrinkage, and reduce biodiversity.
5. **Management recommendations**: Implement protection measures including reducing human intervention, increasing pasture restoration, protecting biodiversity, and conducting artificial weather modification in suitable areas to mitigate drought trends.

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Note: Figure translations are in progress. See original paper for figures.